# PATENT SPECIFICATION

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## PROVISIONAL SPECIFICATION

# Improvements in and relating to Hot Air Power Plant

I, JOHN SUTHERST BRUCE, of 305, Broadway, Cullercoats, in the County of Northumberland, a British subject, do hereby declare the nature of this invention to be as follows:—

This invention relates to hot air power plant, and has for its object to provide an improved arrangement and method of working.

According to my invention, the compressed air to be expanded in the hot air engine is heated in apparatus, subsequently referred to as the hot-air generator, provided externally of said engine, and the expanded air exhausted from said engine is utilised to heat the air for the combustion of the fuel used in the hot-air generator, or as the combustion air itself, thus reducing to a minimum the power losses due to unused heat.

The hot-air generator is arranged so that the air to be heated is divided into streams of small cross-sectional area; for instance, it may be of tubular type wherein the air for use in the engine passes through tubes surrounded by the products of combustion from an oil-fired or other furnace, and to improve the efficiency of said furnace, a portion of said products which have already been used in the hot-air generator may be mixed with the products in the combustion chamber of the furnace and re-circulated through the hot-air generator. Atmospheric air may be used in the furnace for the combustion of the fuel in the furnace, in which case said air is pre-heated by the exhaust air from the engine, or the exhaust air from the engine may be supplied to the furnace to serve as the combustion air for the fuel. If desired, the products of combustion may also be used to pre-heat the combustion air.

The air used in the engine is compressed in the engine before it is passed into the hot-air generator, the engine preferably being double-acting, and each portion of its cylinder may work on a two- or four-stroke cycle. The air used in the engine may circulate therethrough and through the hot-air generator in a continuous cycle, in which case the working air, after compression in the engine, may be cooled before it enters the hot-air generator by using the air for combustion as a cooling medium. Or the working air may be drawn from the atmosphere and, after compression, heating and expansion, used as the combustion air in the combustion chamber of the hot-air generator, fresh air being drawn into the engine for each compression charge.

The engine may be uncooled or may be cooled by air or water, and, where air is circulated around the engine to cool it, said air may be used for combustion in the hot-air generator furnace after such circulation.

The engine may consist of a single cylinder in which the complete expansion is effected, or of two or more such cylinders, or the expansion may take place in two or more cylinders in series forming a compound engine.

Governing may be effected by means of a governor operating a throttle valve in the pipe through which the hot compressed passes from the hot-air generator to the engine and/or, where the said hot-air generator is oil-fired or fitted with a mechanical stoker, a governor or thermostatic control may be provided to regulate the supply of fuel or the operation of the stoker.

Compressed air supplied independently of the engine may be used to start the plant and/or to replenish the air in the plant.

The pressure of the working air may be increased in the hot-air generator by dividing the generator into stages with suitable valves between each stage so that the pressure is increased in each stage, the flow of the products of combustion from the furnace being arranged to produce temperatures corresponding with the pressure required in each stage. A relief valve is provided in each stage discharging into the preceding stage, and a safety valve is provided in the initial or low-pressure stage which operates only when full pressure is reached in all the stages. The supply to the engine may be drawn from the final or high-pressure stage, and said outflow arranged to reduce

the pressure in all the stages to permit the admission of low-pressure air without loss of heat.

The generators may each be divided into units, each of which supplies one or more of the cylinders of the engine, and means may be provided for controlling the flow of the products of combustion through individual units.

In cases where the complete plant comprises more than one engine, the compressed air for the complete plant may be supplied to the hot-air generator or generators by less than the total number of engines, the gear operating the control valves in the engine or engines being correspondingly modified for this purpose.

The thermal efficiency of hot air plant herein described will be high, as cooling and exhaust losses are reduced to a minimum. Moreover the engine may be of light weight and can be cheaply produced. It is free from heat troubles, and the only auxiliaries required are those necessary for the supply of fuel to the furnace and of compressed air for starting and replenishing the engine. My improved plant is thus simple, efficient, inexpensive and free from trouble in working.

One example of a plant embodying my invention comprises a hot-air generator and a pair of four-cycle double acting cylinders each provided with mechanically-operated valves at top and bottom, said cylinders at each end having, in sequence, a working stroke, an exhaust stroke, a charging stroke and a compression stroke. The cylinders are fed with hot compressed air from the hot-air generator, the exhaust from the cylinders is led into the furnace of the hot-air generator which is oil-fired, the cylinders draw their charges from the atmosphere, and the compressed air is led from the engine to the hot-air generator through a heat exchanger around which a supply of air is forced by a fan to the furnace to supplement the air for combustion. The products of combustion from the furnace are circulated by a fan around the air-heating elements in the generator, and a portion of said products are returned to the combustion chamber of the furnace for re-circulation.

Dated this 13th day of July, 1937.

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## COMPLETE SPECIFICATION

# Improvements in and relating to Hot Air Power Plant

I, JOHN SUTHERST BRUCE, of 305, Broadway, Cullercoats, in the County of Northumberland, a British subject, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to hot air power plant.

Hot air engines as hitherto constructed work with air at low pressures, both when in compression and after heating, as for example about 15 pounds per square inch above atmospheric pressure, thereby necessitating an engine of very large size considering the power obtained. For example, a power of about 290 I.H.P. was obtained from an engine having four working cylinders each of 14 feet in diameter and four compressing cylinders each 11 feet 5 inches in diameter with pistons having a stroke of 6 feet, the useful mean pressure being about two pounds per square inch. The engines were heavy and cumbersome, and their mechanical efficiencies were low. Owing to the heat being directly applied to the power cylinder walls, the engines were subject to heat troubles which were intensified by the impossibility of water-cooling the cylinders where the heat was applied, as to have done so would have defeated the object of heating them. Moreover, due to the poor heat conductivity of the air, difficulty was experienced in heating all the air in the cylinders. Troubles were also experienced owing to faulty lubrication.

Hot air power plant has however been proposed wherein the normal working medium is air compressed by a hot air engine and heated in apparatus provided externally of said engine, and in such plant the expanded air exhausted from the engine has been utilised to minimise the loss of power in the plant due to unused heat by employing a controllable portion of said exhaust air as forced draught for the fuel in the furnace of the air heater, or by using said exhaust air to pre-heat or assist in pre-heating the working air before the latter passes to the main air heater, and, in the case of tur-

bines operated by an independent supply of super-heated compressed air, it has been proposed to reduce the temperature in the air heating chamber of the super-heater by mixing a portion of the exhaust air with the furnace gases in said super-heater, in which case it has also been proposed to use a portion of the exhaust air to support combustion in the furnace of said super-heater.

The principal difficulty met with in hot air power plant is the temperature of the media used in its operation. In order to provide high efficiencies and consequently a relatively small plant suitable for commercial utilisation, a temperature as high as possible must be used, but the materials obtainable for the construction of the plant have temperature limits above which it is not safe or possible to go; moreover in reciprocating engines there are also temperature limits to the successful working of rubbing parts.

The combustion temperatures of the majority of fuels in commercial use are greater than can be withstood with safety by the constructional materials available unless provision is made to safeguard them. In the internal-combustion reciprocating engine for instance, where combustion at high temperature occurs in the cylinders of the engine itself, the cylinders and pistons of the engine are usually cooled by means of water or oil. Due however to the difficulty of utilising the potential energy absorbed by said cooling media, a considerable portion of the energy equivalent to the available heat generated in the engine is consequently lost.

The object of the present invention is to provide an improved hot air power plant wherein interchange of heat between the working air, the exhaust air and the heating gases used in the plant is arranged to control the temperatures of said air and gases, thereby safeguarding the materials used in the construction of the plant from the deleterious effect of excessively high temperatures whilst at the same time minimising loss of power in the plant due to unused heat.

A further object of this invention is to provide heat exchange apparatus arranged as far as possible as components of a compact unit air heating apparatus to avoid loss of power due to fall of pressure or by radiation or conduction of heat to the surrounding atmosphere and to reduce weight and space occupied.

Hot air power plant in accordance with this invention is of the kind wherein the working air is compressed in the power cylinder or cylinders of a hot air engine or in a compressor or compressors incorporated in the said plant and driven by said engine, said working air being heated in air heating apparatus provided externally of said engine, and wherein the expanded air exhausted from the engine is utilised as the combustion air for the fuel used in said air heating apparatus and to control the temperature of the heating gases in said apparatus to a safe temperature, and is characterised by the provision, as an integral part of said air heating apparatus, of a heat exchanger whereby said exhaust air, before being used to support combustion and control the temperature in said air heating apparatus, is preheated by the waste gases from the air-heating chamber of said apparatus after said gases have been used to heat the working air, thereby providing an air heating apparatus of compact form wherein the losses of power due to radiation and to the escape of unused heat are minimised, and wherein the temperature of the hot gases from the furnace of said apparatus is controlled.

In the preferred construction, the air heating apparatus is constructed as a unit capable of being controlled as regards the admission of pre-heated exhaust air to the combustion chamber and the admission of hot gases from said chamber to the chamber wherein the working air is heated. Means for controlling the hot air engine by cutting-off or throttling the supply of working air thereto are arranged to operate in conjunction with means controlling the feed of fuel to the air heating apparatus to prevent excessive application of heat to the working air when the supply of air to the engine is reduced.

The engine may be uncooled, or it may be wholly or partially cooled by air or water, and where air is circulated around the engine parts to cool them, said air may be used for combustion in the air heating apparatus after such circulation. If desired, the expanded air exhausted from the engine may be utilised to cool heated parts of the engine before said exhaust air is led to the heat exchanger of the air heating apparatus.

The working air for the engine is drawn continuously from the atmosphere during the operation of the plant, and is returned continuously to the atmosphere after use.

Said working air may be heated at constant pressure, constant volume, or with change in both the pressure and the volume, and may be compressed and expanded isothermally, adiabatically or in conformity with any other convenient exponent of compression or expansion,

the temperature and pressures being arranged to effect the utilisation of the heat in the engine in as efficient a manner as possible consistent with an engine of commercial design.

The apparatus for heating the working air for the engine is preferably arranged so that the air to be heated is divided into streams of small cross-sectional area; for instance, said apparatus may be of tubular type wherein the working air passes through tubes surrounded by the hot gases from an oil-fired or other furnace, or by hot gases from any other convenient source.

If desired, the air heating apparatus may be of the type in which the hot gases from a furnace or other source pass through tubes or the like while the working air to be heated is passed therearound.

If solid fuel is used in the furnace of the air heater and said fuel is fed by hand to the furnace, the latter may be divided into separate units and controls, such as doors or louvres, provided in the passages conveying the air for combustion and for mixing with the hot gases whereby said air may be diverted from any individual furnace unit to enable fuel to be fed thereto without stopping the air supply to the other furnace units of the air heater and without risk of flames being forced from said furnace unit into the atmosphere.

Jets for projecting air under pressure or the like may be provided within the air heater for clearing away soot or other matter which may be deposited on the heat-transmitting elements therein.

It will be understood that a single air heater or any convenient number of air heaters may be provided in the complete hot air power plant.

The hot air engine may be of the reciprocating or of the rotary type or a combination of such types. When of the reciprocating type, the engine may have one cylinder in which the complete expansion and compression of the working air is effected, or it may have two or more such cylinders; or, in order to use high pressure air, said expansion and/or compression may take place in two or more cylinders in series forming a compound or multi-stage engine. The axes of the cylinders of the engine may be arranged vertically, horizontally, radially or at any convenient angle.

When of the reciprocating type, the engine may be of single acting, opposed piston, or double acting type, but preferably it is of the last-named type. The cylinders of the engine may work either on a two-stroke or a four-stroke cycle.

In the case of an engine working on a two-stroke cycle, the compressor cylinders may be separate from the power cylinders, or a separate scavenging pump or pumps or the like may be provided, each power cylinder of the engine having one power stroke and one exhaust stroke from each end of the cylinder during each revolution. In the case of an engine working on a four-stroke cycle, the engine cylinders are used for power and for compressing purposes alternately, and the engine has one power stroke from each end of each cylinder during each two revolutions, the other strokes being successively exhaust, suction and compression strokes; separate air compressing cylinders or scavenging pumps or the like are not then required.

The admission of working air to and the exhaust of the expanded air from the power cylinders of the engine during each revolution of the engine, where said engine is of the reciprocating type, is effected in any suitable known manner; for example, by means of slide valves actuated by eccentrics fixed on the power shaft of the engine which transmit their movements through Stephenson link motion; by means of mushroom type valves actuated by cams driven by the power shaft; or any other suitable means. The means for effecting the distribution of the working air may be arranged in known manner so that the engine can be caused to transmit its rotary motion in either clockwise or anticlockwise direction, i.e. be reversible.

Where the working air is not compressed in the power cylinders of the engine but in an air compressor or compressors incorporated therein and driven from the power shaft of the engine, the compressor may be of the reciprocating type with cylinders arranged side by side with the power cylinders or in tandem therewith, and may be varied in construction in similar manner to the engine, or the compressor may be of the rotary type, or of combined rotary and reciprocating type. For example, the lower stage or stages may be of rotary type and the higher stage or stages of reciprocating type.

The compressing portion of the engine may be cooled, if desired, and where such cooling is effected it is preferably carried out at a stage when a minimum amount of work has been applied to the working air; for example, before compression, in the early stage or stages of compression, and, where compound or multi-stage compression is used, between the stages of compression.

To enable air of high temperature to

be employed in the engine cylinders when said engine is of the reciprocating type, the pistons in and the distribution valves of said cylinders may reciprocate with small clearances between them and the internal peripheries of the cylinders and valve chambers respectively, and, for the purpose of guiding the said pistons and valves without employing tail rods passing through the covers of the said cylinders and chambers, auxiliary cylinders having close-fitting pistons and valves are arranged in tandem with the high-temperature cylinders, the pistons and valves respectively of each pair being rigidly connected together. With this arrangement, the high temperature air may be admitted into the chamber and cylinder of each pair in which respectively the valve and piston having clearance is provided, the close-fitting valve and piston of the other cylinder of said pair serving as guides. The cylinders have close-fitting pistons and valves may be used for working air of lower temperature, or, when the compressing cylinders are arranged in tandem with the working cylinders, they may be used as guides.

Manual control of the speed and power developed by the plant may be effected by means of a stop valve and/or throttle valve in the pipe through which the hot compressed air passes from the air heating apparatus to the engine and/or by suitable means operating on the mechanically-operated valves which control the admission of working air to the engine, as for instance by adjusting the position of the Stephenson link motion where such is fitted. In order to prevent excessive heat being applied to the working air in the air heating apparatus, when the supply of air passing therethrough is reduced and where the said apparatus is oil-fired or fitted with a mechanical stoker, the means for controlling the power of the engine may be arranged to operate in conjunction with the means controlling the admission of oil fuel to the air heater or the feed of the stoker.

If desired, controls such as doors or louvres may be provided for shutting-off and diverting the flow of the hot gases in the air heater so that they do not come in contact with the heating elements of the said heater when the flow of working air therethrough is reduced, and, if desired, these means may be arranged to be operated in conjunction with the control of the engine.

Governing of the engine may be effected by means of an inertia or other type of governor operating on the controls of the engine and air heating apparatus as described above and/or by thermostats placed in the paths of the air-heating gases in the air heater and operating on said controls.

Compressed air supplied independently of the engine-driven compressor may be used to replenish air lost during the operation of the plant and/or to start the plant in the first instance, and the control of such independent air supply may be arranged to be operated in conjunction with the control of the engine and/or air heater so that air may be continuously supplied to the heater so long as fuel is being burned therein.

The hand and/or governor controls may be effected by mechanical means, or by pneumatic, hydraulic or electrical relays in known manner.

If the number of cylinders and the ratio of cut-off in the engine are such as to cause difficulty in the starting of the engine through the distributing valves, a starting supply of working air may be led directly from the air heating apparatus to the top and/or bottom of one or more of the power cylinders of the engine.

It will be understood that the materials used in the construction of my improved hot air power plant are such as are suitable for the conditions under which the plant operates, and that all necessary pipes, fittings and connections are provided. The engine is arranged for suitable lubrication, draining and the like, and all surfaces of the plant which may radiate heat are covered with non-conducting material in a suitable manner. The pressure portion of the air heating apparatus is provided with suitable stop valves or other means for controlling the admission and the exit of the working air; with safety valves; and with gauges for indicating the temperature and pressure of the working air.

The thermal efficiency of hot air plant as herein described will be high, as cooling and exhaust losses are reduced to a minimum. Moreover the engine may be of light weight and can be cheaply produced. As the pressures and temperatures of the working air are controlled to suit the materials and conditions of the engine, it can be made free from inherent heat troubles, and the only auxiliaries required are those necessary for the supply of fuel to the furnace and of compressed air for starting and replenishing the engine. My improved plant is thus simple, efficient, inexpensive and free from trouble in working.

The accompanying drawings illustrate diagrammatically and by way of example one construction of hot air power plant

embodying my invention. In the drawings

Figures 1 and 2 are a side elevation and a plan respectively;

Figure 3 is a front elevation of the engine and air compressor; and

Figure 4 is a sectional elevation of the hot-air heating apparatus to a larger scale.

In Figs. 1, 2 and 4 the arrows indicate the direction in which the compressed air travels.

Figure 5 is the theoretical indicator diagram for the engine illustrated in the above figures.

Figure 6 is a sectional elevation illustrating diagrammatically an alternative arrangement of air-compressing and power cylinders.

In the plant illustrated in Figs. 1 to 4 of the drawings, the power cylinders of the engine are of the two-stroke cycle double-acting type (i.e. there is one power stroke and one exhaust stroke per revolution from each end of each power cylinder). It will be understood that the governing factor in the design of the plant is the temperature to which the working air is heated, and that this temperature is governed by the materials available for the construction of the plant and the lubrication of the engine. As it is desired to reduce thermal losses in the plant to a minimum, artificial cooling of the engine is avoided as much as possible, and, in the example shown, the engine power cylinders are not cooled and a temperature of 850° F. has been selected for the working air when it leaves the air heating apparatus. The working pressure is 165 pounds per square inch (absolute) in order to deal efficiently with the said temperature. The working air is expanded substantially adiabatically in the engine to substantially atmospheric pressure, the exhaust temperature being about 200° F. The mean temperature in the power cylinders is hence about 525° F. The working air is drawn from the atmosphere and compressed to the working pressure in two stages, being cooled in the first stage and between the first and second stages of compression. The working air is heated in the air heating apparatus at substantially constant pressure. It will be understood that the above figures are given as representing a typical example and need not be adhered to in every instance.

Referring now to the drawings, in the plant indicated in Figs. 1 to 4, $a$ are the four power cylinders of the hot air engine, said cylinders being all of the same size and the expansion of air from working pressure to exhaust being carried out in each individual cylinder. $b$ are chambers housing mechanically-operated valves of suitable type controlling the admission and exhaust of air to and from said power cylinders.

The air-compressing cylinders are double-acting and are arranged in sets of two disposed in tandem, each set comprising a low-pressure cylinder $c$ and a high-pressure cylinder $c^1$. $d$, $d^1$ are the valve chambers for said cylinders and house spring-loaded automatic type or mechanically-operated valves of suitable type which control the admission and discharge of air to and from said cylinders.

The pistons of the power cylinders $a$ drive a power shaft $e$ through connecting rods and cranks in the customary manner, and the pistons of the air-compressing cylinders are similarly driven from an extension of said power shaft, the relative disposition of the crank angles and their weights being arranged to give a balanced drive. The distribution valves in the chambers $b$, $d$ and $d^1$ are operated from the power shaft $e$ in known manner where these valves are of mechanically-operated type. A flywheel $e^1$ may be provided on the power shaft.

The air which is compressed in two stages is cooled in the first stage by water circulated through jackets around the low-pressure cylinders $c$, said water being circulated by a pump (not shown) preferably driven by the engine. A suitable intercooler is provided as indicated at $c^2$ (Fig. 2). The compressed air from the high-pressure cylinders $c^1$ is led by discharge pipes $f$ to an oil-fired air heating apparatus $g$. Oil separators $f^1$ may be provided in the pipes $f$, and a compressed air reservoir $f^2$ is introduced between the compressor and the air heater. An automatically or manually controlled independently driven air compressor $f^3$ (Fig. 2) is provided to supply compressed air to the reservoir $f^2$ for starting and replenishing purposes.

The compressed air from the compressor is passed under the control of a valve $g^1$ through a series of coils $g^2$ within the casing of the air heater $g$ and thence through a control valve $g^3$ into a supply pipe $g^4$ past a control valve $g^5$ and through an expansion piece $g^6$ to branches $g^7$ leading to the valve chambers $b$ of the engine. A reservoir for hot compressed air may, if desired, be introduced into the pipe $g^4$.

The valve $g^5$ controlling the inlet of hot compressed air to the engine cylinders $a$ is operated by a handwheel $h$ on a vertical rod $h^1$ coupled by bevel gearing $h^2$ and a clutch $h^9$ (Fig. 1) to a shaft $h^6$

which in turn is coupled by bevel gearing $h^3$ to shafts $h^4$, $h^5$ respectively. The shaft $h^4$ is connected through a clutch $h^7$ to the valve $f^4$ in the pipe $f^3$ (Fig. 2) connecting the independent air compressor $f^1$ to the air reservoir $f^2$. The shaft $h^5$ is connected to a valve $h^8$ which controls the supply of liquid fuel to the burners $m$ of the air heater $g$. The arrangement is such that the handwheel $h$ which controls the engine can be used to control simultaneously the fuel supply to the air heater and, for starting and manœuvring purposes, also the independent compressed air supply to the air heater.

The exhaust air from the engine cylinders $a$ is conveyed from the valve chamber $b$ by branch pipes $j$ fitted with expansion pieces $j^1$, and a portion of said air, controlled by a valve $j^2$, is exhausted to atmosphere or elsewhere through a pipe $j^3$ while the remaining portion of the exhaust, under the control of a valve $j^4$, is led to the air heater $g$ by pipes $j^5$ which pass the exhaust air through a heat exchanger $k$ in the exit $k^1$ from the casing of the heater through which the hot gases escape to the atmosphere. The exhaust air is thus heated by the waste gases from the air heater and passes by pipes $j^6$ to the combustion chamber $n$ of the heater as shown in Fig. 4. The temperature of the air delivered to the combustion chamber $n$ may be further raised by circulation in said chamber which is lined with refractory material $n^1$. A portion of the exhaust air is also led by a branch $j^7$ of the pipe $j^5$ and ducts $j^8$ to the oil burners $m$ to provide the necessary air for primary combustion. The coils $g^2$ in the air heater are heated by the hot gases mixed with the heated exhaust air entering the combustion chamber $n$ through the pipes $j^6$. $n^2$, $n^3$ are control doors operated in unison whereby the pipes $j^6$ can be closed and hot gases from the furnace $n$ can be diverted to atmosphere through the pipe $n^4$ when desired. The doors $n^2$, $n^3$ may be operated in conjunction with the engine control $h$.

The exhaust air escaping by the pipe $j^3$, instead of being led to atmosphere, may be utilised for heating purposes in the building or ship in which the plant is situated.

It will be observed that the heat imparted by the air heating apparatus $g$ to the compressed air from the compressor cylinders $c$, $c^1$ is primarily utilised to produce power in the power cylinders $a$ of the engine, and the heat remaining in a controlled portion of the exhaust air therefrom is utilised to increase the heating capacity of the air heater thereby increasing the thermal efficiency of the plant to a maximum and reducing heat losses to a minimum.

Fig. 6 illustrates an alternative arrangement of engine having air-compressing and power cylinders in tandem to enable air at high temperature to be employed. In this example, $a^1$, $a^2$ are the power cylinders and $p$, $p^1$ are high-pressure and low-pressure air-compressing cylinders respectively. The power cylinders are fitted with liners and with pistons $r$ with clearances between them and the internal peripheries of said liners. The admission and discharge of hot air from the power cylinders are controlled by piston valves $s^1$ in valve chambers $s$, said valves being also provided with clearance. The air-compressing cylinders are provided with close-fitting pistons $t$, $t^1$, and admission and discharge of air to said cylinders are controlled by close-fitting piston valves $u^1$ in valve chambers $u$. The pairs of pistons and valves are rigidly connected together by rods $v$, $v^1$ and $v^2$ respectively as shown so that the close-fitting pistons and valves serve to guide the pistons and valves having clearance. The glands $w$ and the cylinder covers $w^1$ of the power cylinders are provided with closed spaces around which exhaust air from the engine or other cooling medium is circulated to cool said glands and covers, and cooling spaces $w^2$ are also provided in the cover of the cylinder $p^2$ and around said cylinder.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. Hot air power plant of the kind herein referred to characterised by the provision, as an integral part of the external air heating apparatus, of a heat exchanger whereby the expanded air exhausted from the engine, before being used to support combustion and control the temperature in said heating apparatus, is pre-heated by the waste gases from the air-heating chamber of said apparatus after said gases have been used to heat the working air.

2. Hot air power plant as claimed in claim 1 wherein the air heating apparatus is constructed as a unit capable of being controlled as regards the admission of pre-heated exhaust air to the combustion chamber and the admission of hot gases from said chamber to the chamber wherein the working air is heated.

3. Hot air power plant as claimed in claim 1 or 2 wherein means are provided for controlling the hot air engine by cutting-off or throttling the supply of working air thereto, said means being

arranged to operate in conjunction with means controlling the feed of fuel to the air heating apparatus to prevent excessive application of heat to the working air when the supply of air to the engine is reduced.

4. Hot air power plant as claimed in claim 1, 2 or 3 wherein controls such as doors or louvres are provided in or adjacent to the combustion chamber of the air heating apparatus for shutting-off and diverting the flow of pre-heated exhaust air to the combustion chamber and of hot gases from said chamber to the air-heating elements of said apparatus.

5. Hot air power plant as claimed in claim 4 wherein the means for operating the controls such as doors or louvres are arranged to operate in conjunction with means for controlling the hot air engine by cutting-off or throttling the supply of working air thereto.

6. Hot air power plant as claimed in any of the preceding claims wherein expanded air exhausted from the engine is utilised to cool heated parts of said engine before said exhaust air is led to the heat exchanger of the air heating apparatus.

7. Hot air power plant as claimed in any of the preceding claims wherein clearance is provided between the pistons in the engine cylinders and the distributing valves thereof and the inner peripheries of said cylinders and the valve chambers respectively, and said pistons and valves are guided by being rigidly connected to close-fitting pistons and valves in auxiliary cylinders in tandem with said engine cylinders and distributing valve chambers respectively.

8. The improved hot air power plant arranged and adapted to operate substantially as herein described and as illustrated diagrammatically in the accompanying drawings.

Dated this 13th day of April, 1938.

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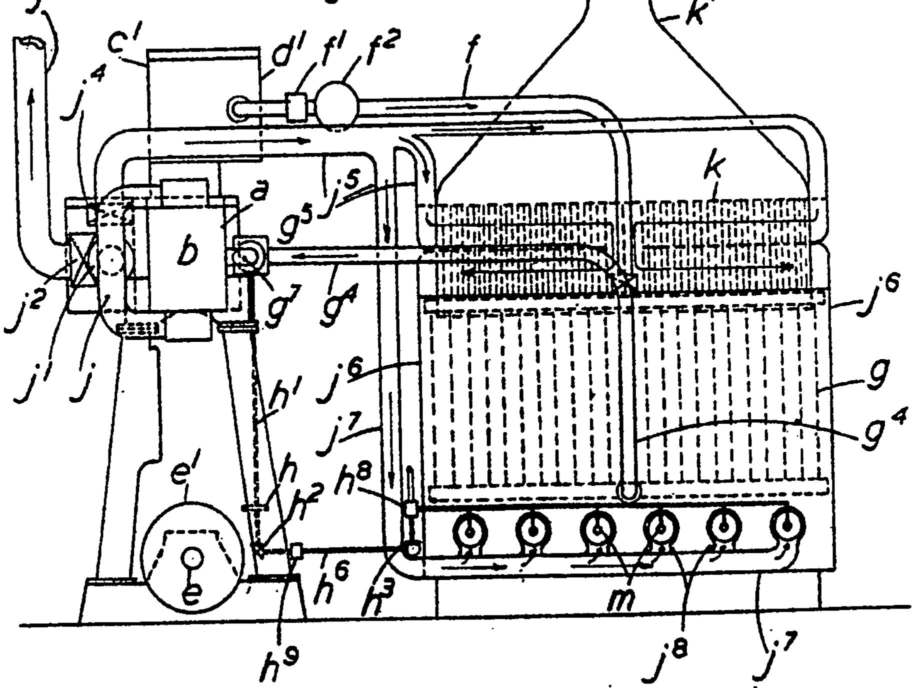
Fig. 1.



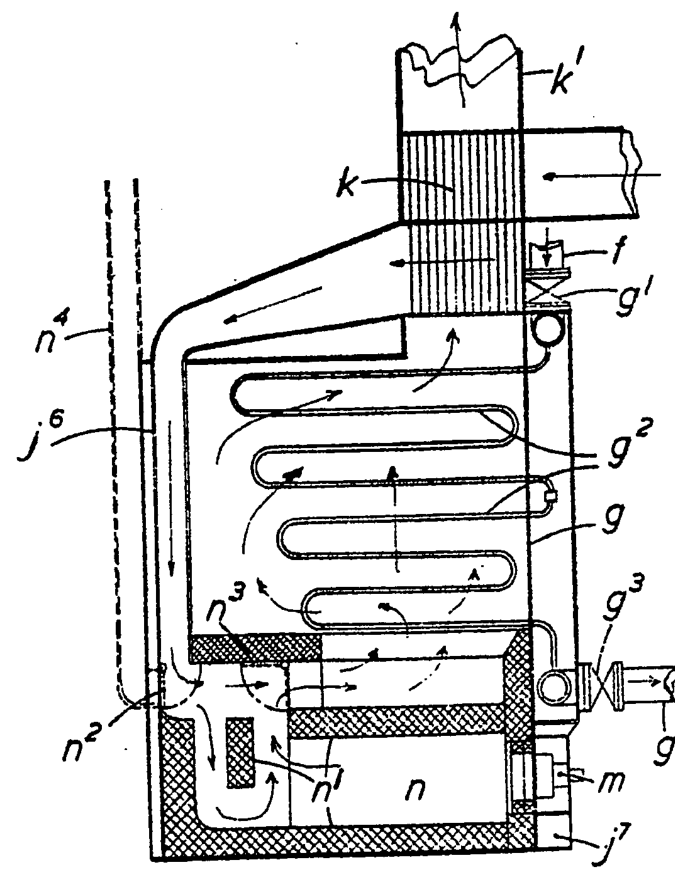
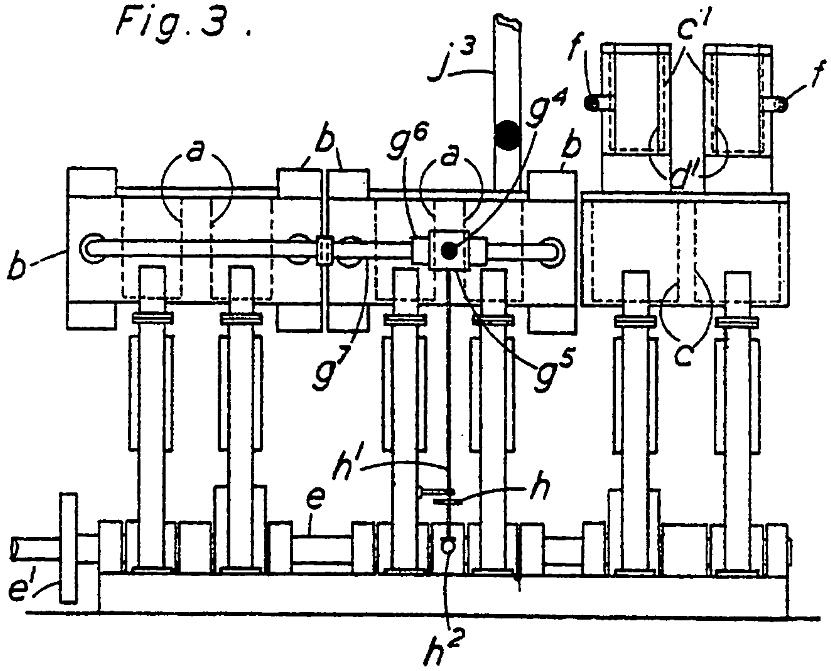




Fig. 4.

[This Drawing is a reproduction of the Original on a reduced scale.]

Fig. 3.



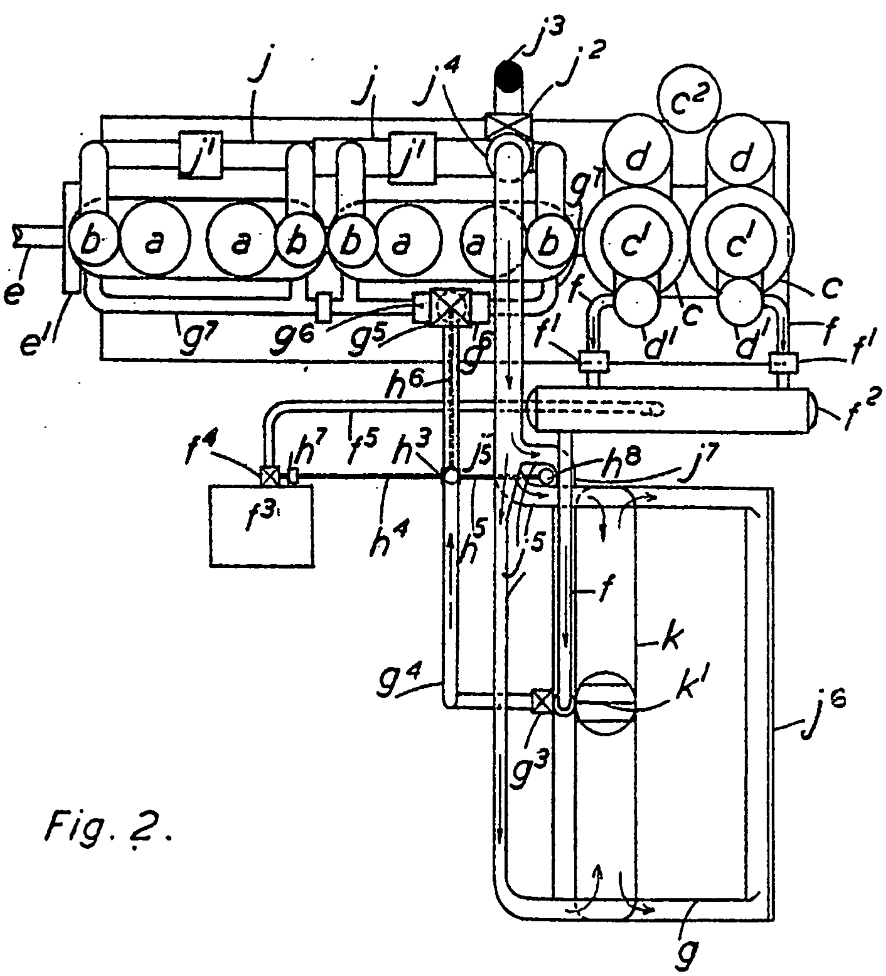




Fig. 2.

Malby & Sons, Photo - Lith

SHEET 1

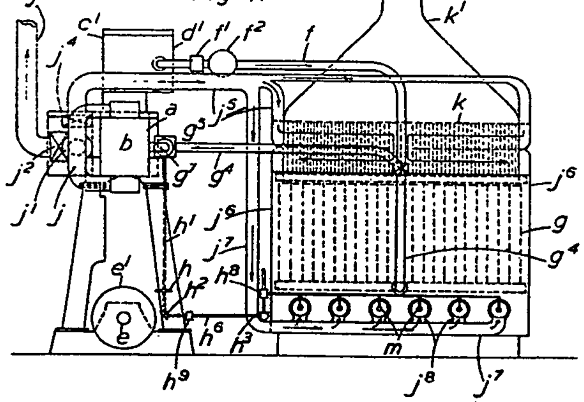


Fig. 1.

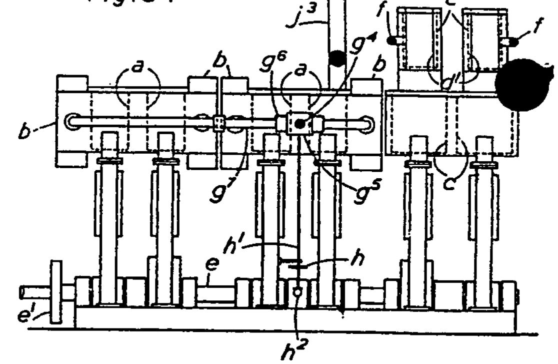


Fig. 3.

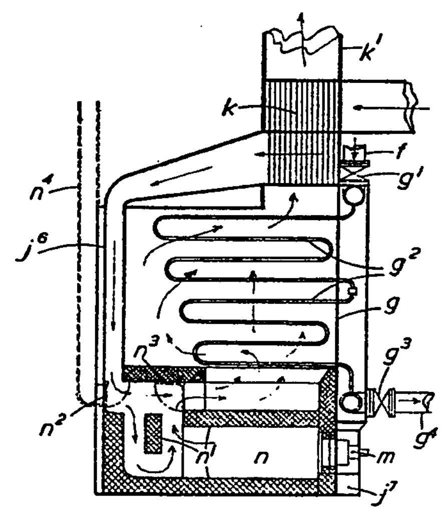


Fig. 4.

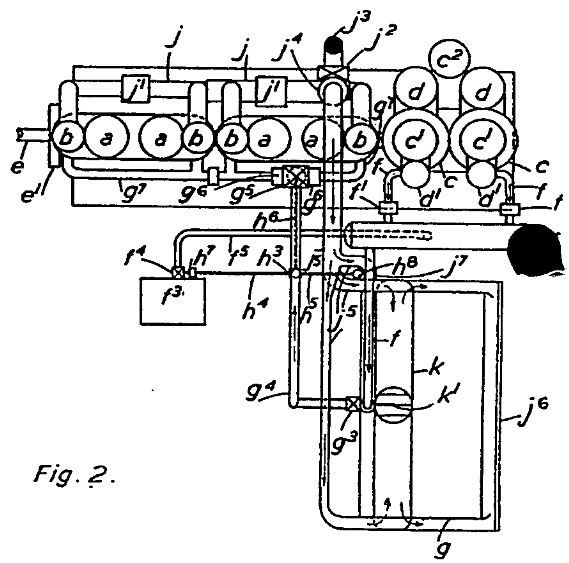


Fig. 2.

[This Drawing is a reproduction of the Original on a reduced scale.]

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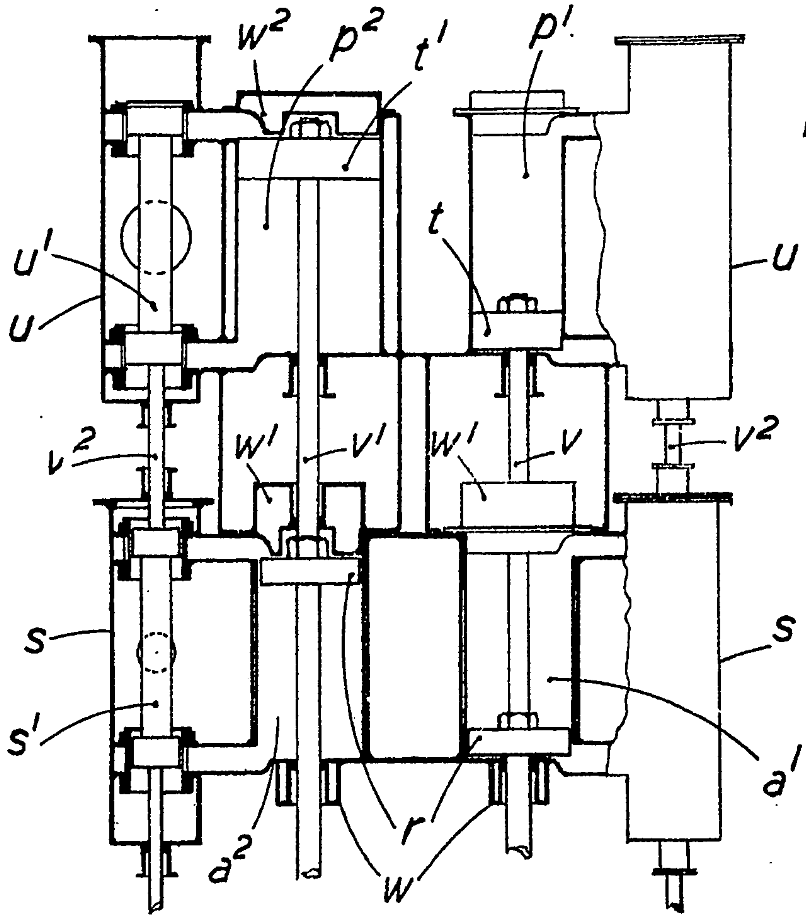


Fig. 6.

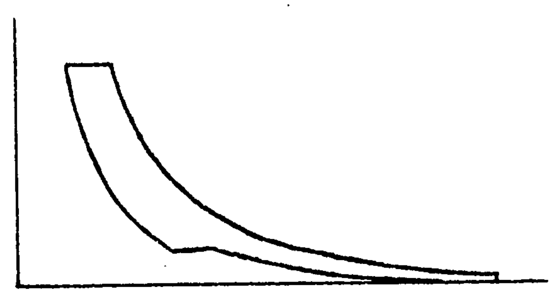

Fig. 5.